Nuclear Instruments and Methods in Physics Research B 331 (2014) 163–167

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Structural, magnetic and magnetoelectric studies of $BaTiO_3$:Co nanocomposite films formed by ion-beam methods

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ARTICLE INFO

Article history:
Received 15 October 2013
Received in revised form 24 January 2014
Accepted 25 January 2014
Available online 13 March 2014

Keywords:
Multiferroics
Ion implantation
Ion beam sputtering deposition
Barium titanate

ABSTRACT

Thin-film samples of ferroelectric barium titanate ($BaTiO_3$) with cobalt nanoparticles were obtained by using either ion implantation or ion beam sputtering deposition (IBSD) techniques. The samples were characterized using X-ray diffraction, transmission electron microscopy, magnetometry and ferromagnetic resonance to investigate the efficiency of above ion-beam methods in the synthesis of magnetoelectric nanocomposite materials. Our structural studies show that high-fluence implantation with Co^+ ions results in the formation of cobalt nanoparticles with mean size of 5 nm in thin surface layer of monocrystalline plate of $BaTiO_3$. On the other hand, larger nanoparticles of cobalt with sizes from 5 up to 40 nm are formed in polycrystalline $BaTiO_3$ matrix only after high-temperature annealing of $BaTiO_3$:Co composite film prepared by IBSD method. Both types of thin-film nanocomposite samples have similar magnetic hysteresis curves in the sample plane. However Co-implanted $BaTiO_3$ reveals strong uniaxial magnetic anisotropy for out-of-plane orientation, while $BaTiO_3$:Co nanocomposite film demonstrates almost isotropic magnetic response. Strong magnetoelectric effect are observed in Co-implanted $BaTiO_3$, and no magnetoelectric coupling are detected in $BaTiO_3$:Co nanocomposite film formed by IBSD with subsequent high-temperature annealing.

1. Introduction

Materials revealing simultaneously ferroelectric and ferromagnetic properties are known as multiferroics [1,2]. The physical coupling between ferroelectric and ferromagnetic sub-systems in multiferroic materials leads to the appearance of the magnetoelectric (ME) effect. Namely, electric polarization in multiferroic materials can be changed by an application of external magnetic field or vice verse the magnetization of the material are changed under an action of electric filed. These effects attract great scientific interest to magnetoelectric materials due to their potential applications in spintronics, sensors and memory devices, etc. However natural single-phase multiferroics reveal weak ME effects or it occurs at temperatures too low for practical applications. At the same time, composite multiferroics which combine two phases (ferromagnetic with ferroelectric ones) show typically giant values of ME effect at room temperature and above [1,2].

A lot of various methods was used to synthesis of thin-film multiferroics based on ferroelectric matrix of $BaTiO_3$ with cobalt nanoparticles, e.g. pulsed laser deposition [3], rf magnetron sputtering [4], sol–gel method [5], chemical solution deposition [6] and laser molecular beam epitaxy [7]. Different magnetic responses and magnetoelectric coupling were observed in these nanocomposites materials in the dependence on synthesis method. Moreover ion-beam methods like ion implantation were used recently also to form nanocomposite layers of $BaTiO_3$ with iron impurity [8,9]. In the given work we used two ion-beam methods (ion implantation and ion-beam sputtering deposition) to form ferroelectric:ferromagnetic ($BaTiO_3$:Co) nanocomposite system. The results of structural, magnetic and magnetoelectric studies are presented to receive new knowledge about ion-beam ways of the synthesis of nanocomposite multiferroics and the nature of magnetoelectric coupling between cobalt nanoparticles and ferroelectric matrix of $BaTiO_3$.

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http://dx.doi.org/10.1016/j.nimb.2014.01.033
0168-583X/